Watershed Function Scientific Focus Area

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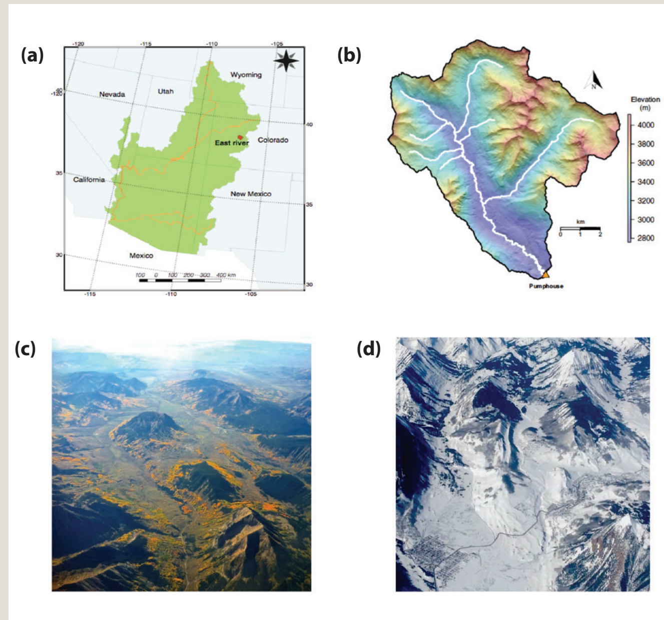
Biogeochemical dynamics from genomes to watershed scales

Extreme weather, climate change, drought, fire, and other disturbances are significantly reshaping interactions within watersheds throughout the world. Watersheds are recognized as Earth's key functional unit for managing water resources, but their hydrological interactions also mediate biogeochemical processes that influence water quality and support all terrestrial life. Complex interactions between microbes, minerals, fluids, dissolved constituents, and plants occur across bedrock-to-canopy and terrestrial-aquatic continuums. These interactions lead to a cascade of effects on downstream water availability, nutrient and metal loading, and carbon and nitrogen cycling. The nature of these interactions, including their response to disturbance, varies throughout the watershed. Despite significant implications for energy production, agriculture, water quality, and other societal benefits important to U.S. Department of Energy (DOE) energy and environmental missions, uncertainty associated with predicting watershed hydro-biogeochemistry and its dynamic response to disturbance remains high. To address this uncertainty, the Subsurface Biogeochemical Research program within DOE's Office of Biological and Environmental Research (BER), is supporting the Watershed Function Scientific Focus Area (SFA).

Watershed Function SFA research focuses on the snow-dominated, high-elevation East River Watershed of the Upper Colorado River Basin. Streamflow originating from snowpack feeds much of the Colorado River, which in turn provides water to one in 10 Americans across seven western states and hydroelectric power to millions, irrigates over 5.5 million acres of agriculture, and supports over $1 trillion per year of economic activity. The complexity and vulnerability of this river basin to disturbance are emblematic of other high-mountain regions worldwide.



East River Watershed. (a) *Watershed location within the Upper Colorado River Basin;* **(b)** *elevation map;* **(c)** *aerial view of the East River during the growing season (courtesy Joseph Guardiola); and* **(d)** *aerial view during the winter season (courtesy Sam Faivre). [Reprinted via a Creative Commons license (CC BY-NC-ND 4.0) from Hubbard, S. S., et al. 2018. "The East River, Colorado, Watershed: A Mountainous Community Testbed for Improving Predictive Understanding of Multiscale Hydrological-Biogeochemical Dynamics,"* Vadose Zone Journal, *DOI:10.2136/vzj2018.03.0061.]*

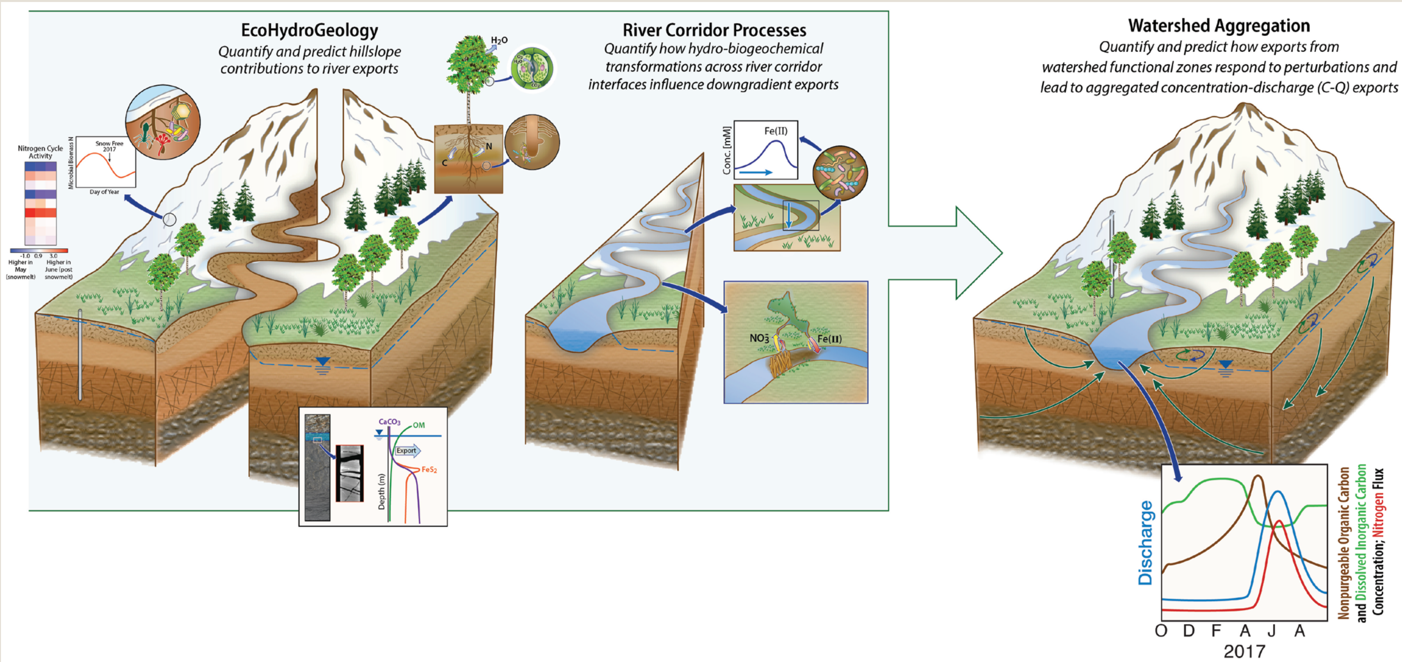
Functional Zone and Scale-Adaptive Approaches

The Watershed Function SFA is advancing a functional zone approach to improve characterization and modeling of hydro-biogeochemical processes within the enormously heterogeneous East River Watershed. This approach first classifies the watershed into parcels that have unique distributions of bedrock-through-canopy properties relative to neighboring regions, and then explores how representative zones contribute to the aggregated watershed concentration-discharge signature. To characterize the watershed organization and associated properties, remotely sensed and ground-based information are used to develop a four-dimensional (4D) East River Watershed digital twin, and machine-learning approaches are used to identify distinct zones. Working within representative hillslope and river corridor zones across the watershed, process-based investigations paired with mechanistic models are advancing an understanding of key processes and their couplings. Examples include investigations of plant and microorganism assimilation, mobilization and transformation of water and nutrients, and bedrock weathering within representative hillslopes, as well as hydrological connectivity and biogeochemical reactions across representative river corridor elements that contribute to river water quality. A scale-adaptive watershed simulation capability (SAWaSC) is

SFA Grand Challenge and Priorities

The Watershed Function SFA is developing a predictive understanding of how mountainous watersheds retain and release water, nutrients, and metals, with a focus on the impacts of droughts, floods, early snowmelt, and other perturbations on downstream water availability and biogeochemical cycling over subseasonal, seasonal, and decadal timescales.

The current phase focuses on addressing how snow accumulation and distribution and snowmelt timing influence watershed hydro-biogeochemical dynamics through three research priorities: predicting how snow dynamics impact aggregated water (Priority 1) and nitrogen (Priority 2) exports, and defining and testing a functional zone approach (Priority 3) for enabling tractable characterization and prediction of aggregated exports in response to snow dynamics.



Predictive Understanding of Complex Mountainous Watersheds. *The aggregated concentration-discharge (C-Q) response of mountainous watersheds to snow dynamics involves a variety of multiphysics, multiscale processes occurring from bedrock to canopy, across land-water interfaces, and along steep hydro-biogeochemical gradients. The Watershed Function SFA is developing an extensible functional zone approach and new capabilities to quantify these interactions, with the goal of predicting aggregated water and solute exports accompanying disturbance. Process-based investigations are paired with mechanistic models to discover how microbe-plant-soil-bedrock-fluid processes occurring within distributed hillslope and river corridor zones respond to snow variability. Transferable new approaches are being developed for predicting how zone-based exports aggregate to a cumulative watershed C-Q response, including scale-adaptive and functional zone simulation approaches.*

being developed to enable "telescoping" into regions that may have an outsized impact on larger watershed response to snow dynamics. Together, the functional zone and scale-adaptive approaches are expected to provide novel, site agnostic, and computationally efficient means for predicting hydro-biogeochemical changes in complex watershed behavior in a manner that is scalable from watersheds to basins.

Collaborative Watershed Science

Led by Berkeley Lab, the multidisciplinary, multi-institutional SFA combines expertise in reactive transport and watershed modeling, environmental genomics and ecosystems biology, plant physiology, environmental geophysics, vadose zone hydrology, low-temperature and isotope geochemistry, data science, and environmental synchrotron science. The project involves key collaborations with investigators from three national laboratories, 28 universities, six federal and state agencies, three local stakeholders, and six small businesses, providing extensive leveraging of support from BER and others.

Alignment with BER Grand Challenges

The Watershed Function SFA is particularly well aligned with three of the grand challenges being addressed by BER's Earth and Environmental Systems Sciences Division. These include the Integrated Water Cycle, Biogeochemistry, and Data-Model Integration challenges. The project's basic research also has relevance to many broader themes, including water in the West, integrated mountainous hydrology, and changing hydrology and water quality. In addition to the SFA's expected scientific outcomes, the project is committed to building community, capacity, and a distributed watershed philosophy.

See the SFA Project Videos!

Introduction | Plants as Sensors | Two Nitrogen Worlds | 4D Digital Watershed

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